Original Clinical Article

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Ultrasound as a diagnostic tool for femoral head containment disorders in children between one and 12 years of age

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Abstract

Purpose Ultrasound has been used to diagnose hip dysplasia in neonates and to screen until the end of their first year. For older children, femoral head containment disorders such as developmental dysplasia of the hip, Legg-Calvé-Perthes disease or cerebral palsy are usually diagnosed with plain radiographs. The aim of the present study was to evaluate ultrasound in comparison with radiographic imaging in children up to age 12 years and to determine reference values for sonographic containment parameters.

Methods Hip ultrasound and radiographic imaging were acquired on the same day and then compared. As a reference, normal acetabular angle and acetabulum head index were determined on radiographs. Lateral cartilage distance (LCD), lateral head distance (LHD) and femoral head extrusion angle (HA) were measured on ultrasound images.

Results We included 96 patients with 167 healthy hips in the study. A total of 55 patients were female and 41 male. The mean age was 5.2 years (sd 3.3; 1.0 to 11.9). $LCD_{ultrasound}$, $LHD_{ultrasound}$ and $HA_{ultrasound}$ correlated significantly with radiographic parameters. The following ultrasound values were calculated as limits for impending loss of containment: $LCD_{ultrasound} \geq 6.5$ mm, $LHD_{ultrasound} \geq 3.3$ mm and $HA_{ultrasound} \geq 27.6°$.

Conclusion Ultrasound is a simple, radiation-free diagnostic tool to detect femoral head containment disorders, even in children older than one year. This study provides reference values for hip ultrasound in children up to 12 years.

Level of evidence: III

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Keywords: ultrasound; hip dysplasia; acetabular head index; hip angle; femoral head extrusion angle

Introduction

A hip ultrasound examination is a widely accepted screening test to exclude hip dysplasia in neonates. As acetabular roof development is pronounced in the first six months, dysplasia or displacement can only be properly diagnosed and treated if they are detected early. Below the age of 12 months, important parts of the pelvis and hip are still cartilaginous. Therefore, Graf introduced real time ultrasonography for the diagnosis of hip dysplasia and this has led to marked improvements in the diagnosis and follow-up of neonates with hip dysplasia.[1,2]

Ultrasound is an affordable and widely available diagnostic tool. Its most important advantage is that it does not expose children to radiation. In children older than 12 month of age, plain radiographs are the primary diagnostic tool for the classification of hip development disorders, although radiation exposure should be avoided at all ages.

A diagnostic tool is especially needed for the detection of lateral subluxation of the femoral head, as this is commonly seen in children with developmental dysplasia of the hip (DDH), Legg-Calvé-Perthes disease or cerebral palsy. Lateral displacement of the femoral head indicates that the clinical course may be unfavourable. This lateralization may be detected on plain radiographs by determining the acetabulum head index.[3] The best-known classification for DDH in radiographs was introduced by Tönnis.[4]

While working with ultrasound in the follow-up examinations of children with hip disorders, we realized that the

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technique could also be used in older children. The aim of the present study was to evaluate the value of ultrasound as additional diagnostic tool in comparison with radiographic imaging in children up to the age of 12 years and to determine standard values for ultrasound parameters.

Materials and methods

We included 96 patients with 167 hips in the study. In all, 55 patients were female and 41 were male. The mean age was 5.2 years (SD 3.3; 1.0 to 11.9). These patients were examined for significant gait disorders with limping, state after hip pain or suspected hip dysplasia. The radiological and ultrasound examinations were always performed on the same day.

A well-contained hip was diagnosed based on reference radiological values for the acetabular head index (AHI) and acetabular angle (AA). To focus on healthy hips exclusion criteria were: earlier operation on the hip, Legg-Calvé-Perthes disease, persistent hip dysplasia, epiphysiolysis capitis femoris, spinal muscular atrophy and tumour. Patients with closed growth plates were also excluded.

In patients with healed hip dysplasia, both sides were examined. If one side was still affected, only the healthy side was examined.

In order to evaluate the value of ultrasound as an additional diagnostic tool in hip disorders, we compared different indexes/scores. All images were independently (spatially and temporally separated) evaluated by two orthopaedic surgeons. The anteroposterior pelvic radiograph and ultrasound images were evaluated separately. Results of both imaging methods were compared and measurements differing by 1 mm were rated as equal. If the differences were > 1 mm, the arithmetic mean was calculated. In clinical practice, containment loss is only defined when the labrum no longer overlaps. [5,6] However, since the labrum cannot be assessed in radiograph diagnostics, this aspect will not be considered further.

Radiography

AHI_{Xray} on anteroposterior pelvic radiography

The AHI_{Xray}, as introduced by Heyman and Herndon,[3] was measured to assess the coverage of the femoral head by the acetabulum (Fig. 1). Imbalance of the size of the head in relation to the acetabulum or lateral displacement of the head from the depth of the acetabulum can be defined on the basis of the AHI, determined as follows: line A is a horizontal measurement from the innermost surface of the head to a vertical line projected from the outermost surface of the acetabulum. Line B is a similar horizontal measurement from the innermost surface of the head to a vertical line projected from the outermost surface of the head. The index is then x100%.[3]

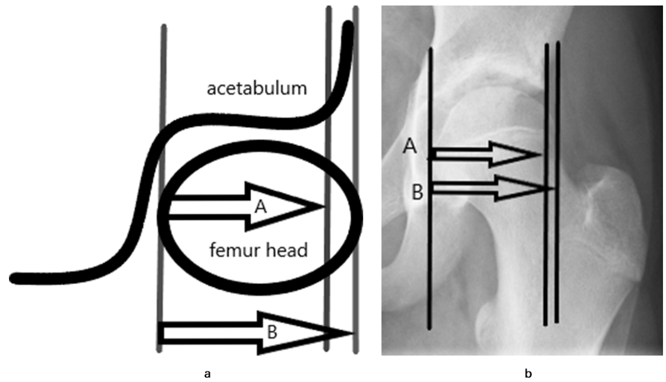

Fig. 1 Acetabular head index as introduced by Heyman and Herndon;[3] x100%; a) scheme; b) radiograph of clinical sample.

The centre-edge angle is often used for the radiological examination of a subluxation of the femoral head. However, this is only reliable if the head is spherical.[7] As this is often not the case, for example, in patients with Legg-Calvé-Perthes disease, the usefulness of this angle is limited. AHI_{Xray} is an alternative for example, Moberg et al[7] proposed that an $AHI_{Xray} \leq 80$ can be used as a reference value for abnormal lateral displacement of the femoral head in children.

AA_{Xray} in anteroposterior pelvic radiography

The AA was measured according to Hilgenreiner,[8,9] as based on the anteroposterior radiograph (Fig. 2). The AA_{Xray} is defined as the angle between the acetabular roof-line and Hilgenreiner's line (the transverse line between the top of the two triradiate cartilages). Tönnis continued to build on these findings.[4] Standard values are age dependent and are listed in the supplementary material. This standard measurement method was used as a reference method.

Lateral head distance in anteroposterior pelvic radiography (LHD_{Xray})

In addition, the LHD (correlates with 'uncovered head') was measured from the anteroposterior radiograph as in Dickens (Fig. 2).[10] A downward vertical line to Hilgenreiner's line was drawn from the lateral edge of the acetabular roof. The distance between this line and the lateral end of the femoral head was measured. Since the measurement is taken from one bony to the other bony reference point, there is thus a clear difference in relation to ultrasound since the cartilaginous portion has no influence. This value serves as a reference value.

Ultrasound

Sonography of the hip was performed with a 9 MHz linear transducer (Logiq 7, GE Healthcare Company, Chicago, Illinois, USA) with a lateral longitudinal plane, according to the guidelines of the German Society for Medical

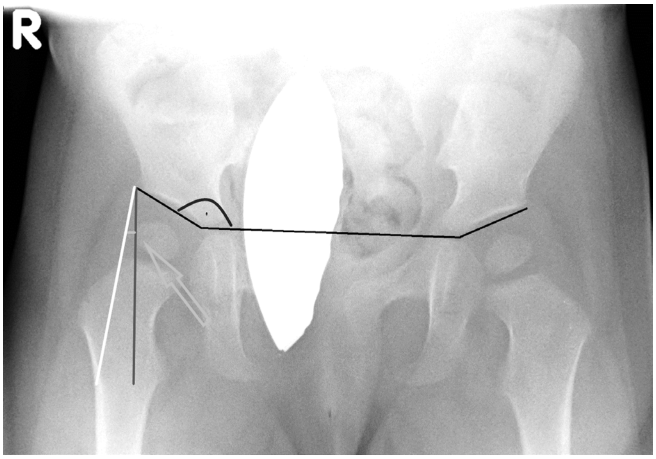

Fig. 2 Radiograph of the hips in a 1.5-year-old girl with unilateral dysplasia of the right hip. In black, presentation of measurement of acetabular angle (angle between the acetabular roofline and Hilgenreiner's line). Lateral head distance in the radiograph is indicated by the light short gray line.

Ultrasound (patient positioned supine in the neutral-zero position). The transducer was kept parallel to the long axis of the patient's body. As the ultrasound image on the monitor screen was rotated 90° in relation to an antero-posterior radiograph, Hilgenreiner's line was vertical and Perkin's line (the line perpendicular to the Hilgenreiner line intersecting the most lateral aspect of the acetabular roof) was horizontal in the ultrasound image. Digital data processing and storage was not possible, all sonographies are available only as paper prints.

Femoral head extrusion angle ($HA_{ultrasound}$) in ultrasound

For the measurement of the femoral head extrusion angle ($HA_{ultrasound}$), a basic line was drawn modified to the Graf technique[11] (in contrast to infants, the lower margin of the os ilium can no longer be visualized in older children due to increasing ossification), parallel to the longitudinal ilium bone in the lateral longitudinal ultrasound image. This line was shifted parallel to the most lateral point of the bony acetabular rim (LA). We then determined the $HA_{ultrasound}$ (in degrees) by drawing a tangent from the LA to the cartilaginous femoral head, i.e. the cartilage capsule border. This border is easily to distinguish, as the cartilaginous femoral head has a low echo and the hip capsule a high echo (Fig. 3).

LHD in ultrasound ($LHD_{ultrasound}$)

We also measured the $LHD_{ultrasound}$ in mm. This was defined as the distance from the lateral tangent of the ossification centre of the femoral head to the Perkins line. When the whole ossification centre was medial to the lateral bony rim of the acetabular roof, we assigned a minus sign to $LHD_{ultrasound}$. (Fig. 4).

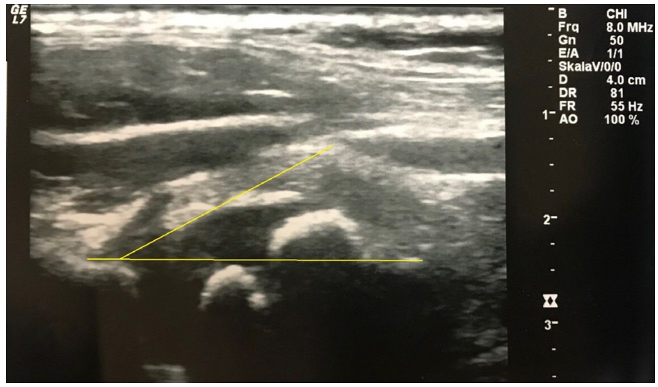

Fig. 3 Typical measurement of the femoral head extrusion angle in a child aged 1.5 years.

Lateral cartilage distance in ultrasound ($LCD_{ultrasound}$)

In addition to the $LHD_{ultrasound}$, we determined the LCD in mm. This was defined as the distance from the lateral tangent of the cartilage-capsule-border of the femoral head to the Perkins line (Fig. 4).

Statistical analysis

Differences between the patients and the three sonographic parameters ($LHD_{ultrasound}$, $LCD_{ultrasound}$ and $HA_{ultrasound}$) were analyzed using contingency tables and chi-square statistics. Whenever the expected numbers in cell entries were < 5, Fisher's exact test was applied to calculate p-values. In order to compare the male and female groups, descriptive statistics were presented as proportions for categorical variables and means plus sd for continuous variables. Intraclass correlation coefficients (ICC) were calculated to evaluate the agreement between the two blinded orthopaedic surgeons (JBG, MHFS)(ICC interpretation: < 0.40, poor; 0.40 to 0.59, fair; 0.60 to 0.74, good; > 0.74 excellent).[12,13]

The sonographic standard parameters were statistically determined from the values for healthy individuals. Therefore, the 97.5 percentile rank was determined from the frequency distribution. Values over the 97.5 percentile rank were thus classified as outside the normal range. In order to decide whether age-dependent ultrasonic standard values have to be derived, significant differences between age groups (0 to 2 years, 2 to 3 years, 3 to 7 years, 7 to 12 years) for the sonographic variables $HA_{ultrasound}$, $LHD_{ultrasound}$ and $LCD_{ultrasound}$ were calculated using analysis of variance. To test whether there is an association between ultrasound and radiograph, the two classification systems were analyzed with the Pearson correlation (r) coefficient with Fisher 95% confidence interval (CI). Finally, AHI_{Xray}, an objective measure in anteroposterior pelvic radiography, served as a dependent variable in a multiple regression to assess the potential predictive impact of $HA_{ultrasound}$, $LHD_{ultrasound}$ and $LCD_{ultrasound}$ in ultrasound. All statistical analyses

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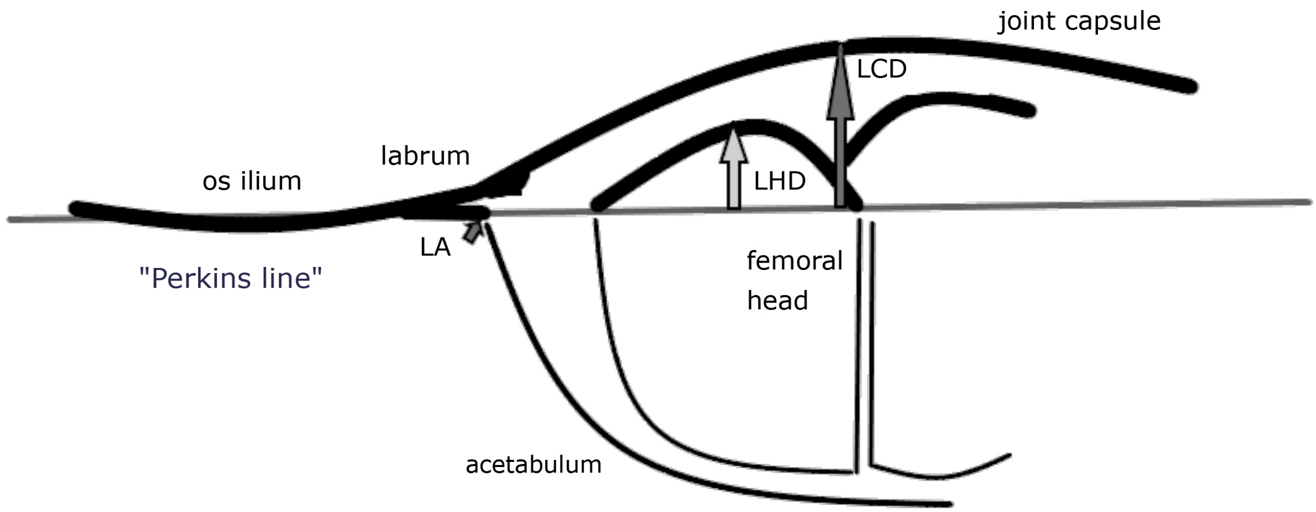

Fig. 4 Schematic drawing of ultrasound of the hip from the lateral aspect. The thin lines represent the parts of the joint not seen by ultrasound. Lateral cartilage distance (LCD), lateral head distance (LHD) and most lateral point of the bony acetabular rim (LA) are indicated.

were performed with the SPSS statistical program 25.0 (SPSS, Chicago, Illinois). A p-value < 0.05 (2-tailed) was considered statistically significant.

Results

We included 96 patients with 167 healthy hips (81 right, 86 left) in the study. A total of 25 hips had to be excluded as they did not correspond to the inclusion criteria. In all, 55 patients were female and 41 male. The mean age was 5.2 years (SD 3.3; 1.0 to 11.9).

The anteroposterior radiography showed a mean AHI_{Xray} of 91.3% (80.1% to 100%), an AA (AA_{Xray}) of 16.7° (5.5° to 27.9°) and a LHD_{Xray} of 2.1 mm (-2.8 mm to 7.3 mm) (Table 1). Age specific results are presented in the supplementary material. The Kolmogorov-Smirnov normality test showed that the hip protrusion angle and the AA were normally distributed.

Ultrasound showed a mean $LCD_{ultrasound}$ of 3.6 mm (0 mm to 8 mm), $LHD_{ultrasound}$ of 0 mm (-4 mm to 4.5 mm) and $HA_{ultrasound}$ angle of 13.6° (-0.1° to 30.0°).

The Kolmogorov-Smirnov normality test showed that the lateral cartilage distance and the femoral head extrusion angle were normally distributed. Age specific results are presented in the supplementary material. We used the following age groups: 0 to two years, two to three years, three to seven years and seven to 12 years. We found significant differences (p < 0.001) between the age groups for $LCD_{ultrasound}$, $LHD_{ultrasound}$ and $HA_{ultrasound}$. Gender-related differences were not detected (p = 0.77). These results indicate that age-dependent standard values must be maintained.

The supplementary material portrays examples of children in different age groups with in each case a healthy and an affected hip, including the case of a child (four years of age) with Legg-Calvé-Perthes disease. After initial values were obtained by radiograph and sonography, the controls were all performed by sonography only. The next radiograph control took place two years later showing reossification phase with no further concern of containment loss.

The frequencies of the ultrasound parameters were analyzed across all age groups. Values over the 97.5 percentile were regarded as being borderline pathological for containment: $LCD_{ultrasound} \geq 6.5$ mm, $LHD_{ultrasound} \geq 3.3$ mm and $HA_{ultrasound} \geq 27.6$ mm. For everyday clinical practice, the age-related standard values presented in Table 2 should be used.

Significant correlations were seen between the results of $LCD_{ultrasound}$ and $LHD_{ultrasound}$ (r = 0.445; 95% CI 0.314 to 0559; p < 0.001), $LCD_{ultrasound}$ and $HA_{ultrasound}$ (r = 0.888; 95% CI 0.851 to 0.917; p < 0.001), $LCD_{ultrasound}$ and AHI_{Xray} (r = -0.338; 95% CI -0.466 to -0.196; p < 0.001) and $LCD_{ultrasound}$ and AA_{Xray} (r = 0.400; 95% CI 0.264 to 0.520; p < 0.001). There was only a weak significant correlation between $LCD_{ultrasound}$ and LHD_{Xray} (r = 0.154; 95% CI 0.002 to 0.299; p = 0.047).

Table 1 Comparison of radiograph and ultrasound results

Radiograph: mean value (range)	Ultrasound: mean value (range)
LHD_{Xray} 2.1 mm (-2.8mm to 7.3 mm)	$LHD_{ultrasound}$ 0 mm (-4 mm to 4.5 mm)
AHI_{Xray} 91.3% (80.1% to 100%)	$LCD_{ultrasound}$ 3.6 mm (0 mm to 8 mm)
AA_{Xray} 16.7° (5.5° to 27.9°)	$HA_{ultrasound}$ 13.6° (-0.1° to 30.0°)

LHD_{Xray}, lateral head distance; $LHD_{ultrasound}$, lateral head distance; AHI_{Xray}, acetabular head index; $LCD_{ultrasound}$, lateral cartilage distance; AA_{Xray}, acetabular angle; $HA_{ultrasound}$, femoral head extrusion angle

Table 2 Age dependent ultrasound results of containment beyond defined threshold range

Age group	Parameter	n	97.5 percentile rank
0 to 2 yrs	$LCD_{ultrasound}$	38	≥ 6.5 mm
	$LHD_{ultrasound}$	38	≥ 1.5 mm
	$HA_{ultrasound}$	38	≥ 30.0°
2 to 3 yrs	$LCD_{ultrasound}$	27	≥ 6.5 mm
	$LHD_{ultrasound}$	27	≥ 1.4 mm
	$HA_{ultrasound}$	27	≥ 30.0°
3 to 7 yrs	$LCD_{ultrasound}$	48	≥ 6.5 mm
	$LHD_{ultrasound}$	48	≥ 6.5 mm
	$HA_{ultrasound}$	48	≥ 23.0°
7 to 12 yrs	$LCD_{ultrasound}$	54	≥ 6.3 mm
	$LHD_{ultrasound}$	54	≥ 3.4 mm
	$HA_{ultrasound}$	54	≥ 24.0°

$LCD_{ultrasound}$, lateral cartilage distance; $LHD_{ultrasound}$, lateral head distance; $HA_{ultrasound}$, femoral head extrusion angle

$LHD_{ultrasound}$ showed significant correlations with all examined parameters ($p < 0.001$).

$HA_{ultrasound}$ showed significant correlations ($p < 0.001$) with $LCD_{ultrasound}$ (r = 0.888; 95% CI 90.851 to 0.917), $LHD_{ultrasound}$ (r = 0.261; 95% CI 0.114 to 0.397), AHI_{Xray} (r= -0.268; 95% CI -0.403 to -0121) and AA_{Xray} (r = 0.495; 95% CI 0.371 to 0.602), but not with LHD_{Xray} (r = 0.017; 95% CI -0.135 to 0.168; p = 0.83).

Multiple linear regression analysis of the parameters $LCD_{ultrasound}$ and $HA_{ultrasound}$ showed excellent correlation, with r = 0.88, so that the two parameters are of equal value in diagnosing a containment problem. In accordance with the requirements of multiple regression, only the variables $LHD_{ultrasound}$ and $HA_{ultrasound}$ were included in the regression analysis. A significant regression equation was found ($p < 0.001$), with a R^2 of 0.253. This corresponds to a strong effect size of Cohen (f) = 0.58. Accordingly, the parameters $LHD_{ultrasound}$ and $HA_{ultrasound}$ significantly influence AHI_{Xray} in anteroposterior radiography. An increase of 10 mm in $LHD_{ultrasound}$ leads to a 18.7% increase in AHI_{Xray}.

The two blinded orthopaedic surgeons (JBG, MHFS) who performed the rating exhibited excellent agreement for the parameters AHI_{Xray} (ICC = 0.98; $p < 0.001$), LHD_{Xray} (ICC = 0.94; $p < 0.001$) and AA_{Xray} (ICC = 0.95; $p < 0.001$).

Discussion

Young children with atraumatic pain of the hip or gait disorders often present in clinical practice. There have, however, been few ultrasound studies with patients older than one year. Ultrasound is routinely used to exclude joint effusions in any age group or to diagnose problems such as bursitis trochanterica. For other questions, radiographs are usually taken. In this study we were able to show that ultrasound is a useful tool to examine the paediatric hip. We were able to find a good correlation between ulrtasound and radiographic findings for prediction of femoral head lateralization and the AHI. Our study was able to compare ultrasonic parameters with the frequently used criteria introduced by Tönnis[4] and Heyman and Herndon[3] in plain radiographs. A recent review concluded that paediatric orthopaedic surgeons must understand the fundamental principles of ultrasonography, with its indications and limitations, if they are to appropriately employ this procedure in the diagnosis and management of DDH.[14] We strongly agree with this assessment and recommend extending the age range for the use of ultrasound for the detection of hip dysplasia from neonates to adolescents. The study results suggest that the use of ultrasound to identify a hip with angles outside the normal range is feasible even after the neonatal period. However, it must be noted that due to growth, the standard values must be adapted depending on age and so the preparation of standard value tables is reasonable for daily routine.

The lack of interobserver reliability is regularly cited with the use of ultrasound. A multicentre study would, therefore, be necessary to confirm the values obtained in this study, but the presented results are in line with the literature. Terjesen et al[15] defined the upper normal limits of $LHD_{ultrasound}$ at 5 mm in children aged two to three years, 6 mm at age four to seven years and 7 mm at age eight to 12 years. Values above these thresholds may indicate hip dislocation. $LHD_{ultrasound}$ increases significantly with age. As all children in our study were healthy only a description of the group is possible. All maximum values were within the reference values of Terjesen.

A few studies have compared ultrasound and radiographs in infants.[16] As shown in Legg-Calvé-Perthes disease, ultrasound is able to detect transient synovitis and an irregular contour of the femoral head. In patients with fragmentation, the altered bone structure is visualized. Lateral protrusion of the head is visualized in ultrasound as increased LCD and LHD values.[17]

The most important advantage of ultrasound is that there is no exposure to radiation, so that the examination may be repeated more frequently. Although MRI also requires no radiation, this may necessitate anaesthesia in young children, which creates further risks. A recent study concluded that ultrasound is useful alternative MRI in studying the containment of the hip.[18]

Taking a radiograph of the pelvis can also be problematic. Repeating the examination to attain the perfect shot is not possible and often there is a need for fixation to avoid tilting or the radiograph protection may slip.

We described a static technique to evaluate the condition of the hips. There are also published reports on dynamic techniques. [19,20] In our clinical practice, we also employ dynamic ultrasound examination in hip abduction, adduction, flexion and rotation, in order to examine whether containment is at risk. The rare clinical finding of 'hinge abduction' is easily confirmed by a dynamic examination. Alamdaran et al[21] were able to show that in their patient group (300 infants, aged nine days to 83 weeks), 100% of hips with dysplastic morphology were unstable in dynamic analysis and 9% of unstable hips had normal morphology in static evaluation. It may then be a valuable approach to compare the plain radiograph with dynamic ultrasound.

Limitations of this study are the lack of a control group and the limited number of patients in each age group. Furthermore, ultrasound may exhibit poor reproducibility. If the ultrasound transducer is angulated relative to the long axis of the patient or somewhat anterior or posterior to the most lateral point of the femoral head, this may lead to discrepancies between the two procedures. Furthermore the lateral bony rim of the acetabulum is sometimes difficult to define.

In conclusion, this study was able to show that ultrasound examination of the hip is not limited to the developing infant hip but also helpful until adolescence. $LDH_{ultrasound}$ and $LCD_{ultrasound}$ have been shown to be comparable parameters with AA_{Xray} and AHI_{Xray}. Ultrasound can be used to identify hips with pathological angles. With sonographic evidence of loss of containment, 3D methods such as MRI or arthrography may be indicated to evaluate whether surgery is necessary and to plan further treatment to prevent irreversible damage to the epiphysis. In addition, ultrasound is a good tool for the follow-up of pathological hips to reduce repetitive radiographic examinations.

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COMPLIANCE WITH ETHICAL STANDARDS

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No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

ETHICAL STATEMENT

Ethical approval: All procedures involving human participants were in accordance with the ethical standards of the institutional and national research committee (reference number: WF-034/20) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards**.**

Informed consent: Informed consent was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

JBG: Conception and design, Acquisition and data, Performed measurements, Drafting of manuscript, Read and approved the final manuscript.

NMJ: Technical support, Drafting of manuscript, Read and approved the final manuscript.

AS: Statistical analysis, Critical revision, Read and approved the final manuscript.

UB: Language editing, Critical revision, Technical support, Read and approved the final manuscript.

FTB: Conception of study, Critical revision of manuscript, Read and approved the final manuscript.

MHFS: Administrative, technical and material support, Performed measurements, Analysis and interpretation of data, Supervision, Read and approved the final manuscript.

SUPPLEMENTAL MATERIAL

Supplemental material is available for this paper at https://online.boneandjoint.org.uk/doi/suppl/10.1302/1863-2548.15.210092

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